

TELEMETRY, TRACKING, AND CONTROL WORKING GROUP REPORT

Richard Campbell, Chairman
Lockheed Missiles & Space Company, Inc.

L. Joseph Rogers, Cochairman
NASA Goddard Space Flight Center

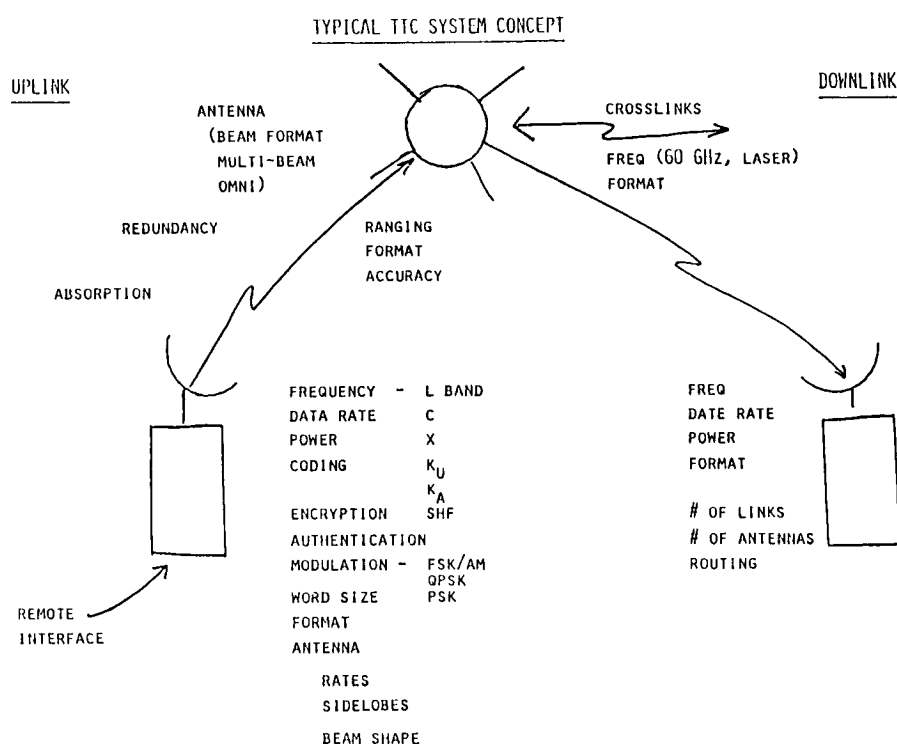
The TTC Working Group consisted of 12 people from NASA and industry. A good representation from industry was present, encompassing both commercial and aerospace interests. The Chairman of this group was Dick Campbell from Lockheed Missiles and Space Company; the Co-chairman was Joe Rogers from NASA-Goddard. The group was chartered to identify the technology needs in TTC for a spacecraft in the year 2000.

TTC WORKING GROUP

NORMAN LANTZ	AEROSPACE CORPORATION
SIDNEY SKJEI	GTE SPACENET
DON NOVAK	COMPUTER SCIENCES CORPORATION
RICHARD CHITTY	FAIRCHILD SPACE COMPANY
JOE BALOMBIN	NASA-LEWIS
ERIC HOFFMAN	JHU/APL
G. "ART" ANZIC	NASA-LEWIS
FRED HAWKES	GOULD COMPUTER SYSTEMS
STANLEY CLARKE	TRW SPACE COMM. DIVISION
JOE ROGERS, CO-CHAIRMAN	NASA-GSFC
REGGIE HOLLOWAY	NASA-LCRC
DICK CAMPBELL, CHAIRMAN	LOCKHEED MISSILES AND SPACE COMPANY

TYPICAL TTC SYSTEM CONCEPT

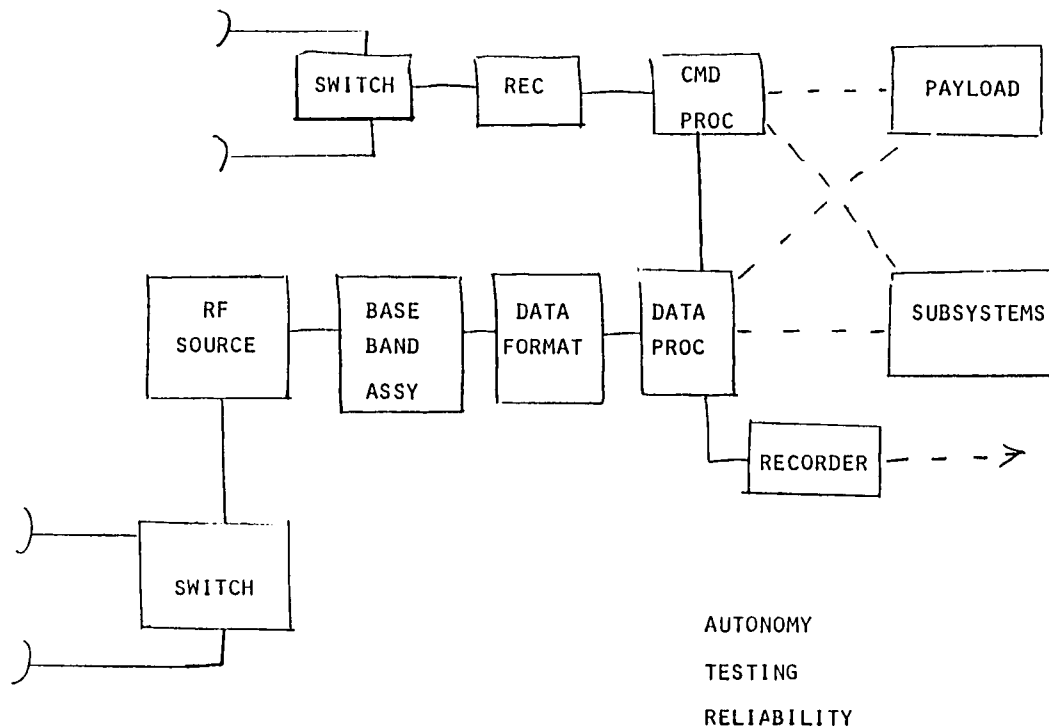
The first action of the working group was to define what it was trying to accomplish. It was concluded that the group should address just TTC and not communications except in the context of TTC. This was in adherence to the ground rules provided to the working group. A typical TTC system was defined, the elements being an uplink and a downlink to the spacecraft, with potential crosslinks to other satellites. The types of elements that were addressed included antennas, transmitters, and receivers. For antennas, several areas were considered such as how beams are formed, whether multi-beams are needed, the directionality of the beams, etc. The operating frequency was addressed, both in microwave and laser regimes. The format of the data and the accuracy of the data were considered, as well as the range of transmission reception. One interesting feature that was identified was that current TTC systems occupy a wide range of frequencies, encompassing L, C, X, KU, KA, and SHF frequency bands. A typical TTC system concept is shown in the figure.



TYPICAL ON-BOARD TTC SYSTEM

The working group tried to define a typical on-board TTC system. The purpose of this was to provide a discussion mechanism to assure that the group addressed all components of a TTC system. A typical TTC system is shown in the figure. The elements that comprise it include antennas, switches, receivers, and transmitters. Included are processing functions to process commands which are then sent to the other elements of the spacecraft, and to process data received from those elements. A data recorder is typically needed to store data for later transmission or for on-board reference. The issues related to such a system include its autonomy, its testability, and its reliability.

TYPICAL ON-BOARD TTC SYSTEM



TECHNOLOGY SELECTION CRITERIA

The working group tried to establish the criteria that would be used in identifying critical technologies. These are listed in the figure and include those general criteria that apply to almost all subsystems. Two criteria, however, specifically related to TTC are apparent which are not generally applicable to other subsystems. The first of these is the frequency assignment for the TTC system. This is an external driver beyond the control of the TTC designer. The other criteria that applies uniquely to TTC is the support system necessary to allow the TTC system to function. The availability and/or feasibility of such a support system is a key ingredient in technology selection.

TECHNOLOGY SELECTION CRITERIA

1. EXTERNALLY DRIVEN FUNCTIONAL REQUIREMENTS
 - TECHNICAL PERFORMANCE (PWR, DATA RATE, ETC.)
 - RELIABILITY
 - COMPATIBILITY
 - FLEXIBILITY/REFORMATTING
2. FREQUENCY ASSIGNMENT
3. SUPPORT INFRASTRUCTURE AVAILABLE
4. PHYSICAL PARAMETERS
5. COST
6. ENVIRONMENTS
7. MISSION LIFETIME
8. ON-ORBIT SERVICEABILITY

KEY TECHNICAL PROBLEMS

After assessing the design implications and the criteria to be used in technology selection, the working group then attempted to define the technical problems that face the TTC area. A significant TTC problem is that the communications spectrum is becoming overloaded. Users require higher data rates with increased bandwidth implications. More and more users are coming on-line, including NASA and DOD programs, commercial satellite systems, and terrestrial systems requiring frequency allocations. All of these users must be channeled into selected parts of the spectrum that are controlled by regulatory agencies such as WARC and the FCC. This crowding of the spectrum makes interference between users more and more an issue.

Another technical problem is the classic issue of reliability and survivability. A TTC system typically requires extremely high reliability. Because of this, the designer likes to continue to use proven concepts and is hesitant about using new technology developments. Another problem defined by the working group was that once installed, a TTC system tends to be inflexible. As with all sub-systems, size, weight, power, and cost are continuing problems.

A number of problems exist with TTC data. Users are demanding greater accuracy and higher resolution. Data compression techniques are often inadequate, and the processing and coding could be improved. Storage of the vast amounts of gathered data continues to be a problem.

The working group was unanimous in the opinion that TTC systems need to have more autonomy. Current problems include lack of fault detection and correction

capability, and automatic operation of the TTC. It was felt that spacecraft generally should be capable of performing their own navigation function, thereby minimizing tracking support.

The working group identified another problem involving the inability to test a TTC system in a space environment prior to its actual utilization as the primary system of a spacecraft.

A final problem that was identified was the lack of design standards for TTC. Everybody designs to their own requirements without regard to other applications. This results in a multitude of designs and typically causes developed items to be inapplicable for new applications.

KEY TECHNICAL PROBLEMS

SPECTRUM OVERLOAD

- HIGHER DATA RATES/MORE BANDWIDTH
- REGULATORY ALLOCATIONS
 - WARC
 - FCC/NTIA
- MORE USERS
 - NASA/DOD
 - COMMUNICATIONS
 - NON-SPACE APPLICATIONS
- INTERFERENCE

RELIABILITY/SURVIVABILITY/PROVEN CONCEPT

SIZE, WEIGHT, POWER

COST

FLEXIBILITY

- PRE-INSTALLATION
- POST OPERATIONAL STATUS

KEY TECHNICAL PROBLEMS (CONT)

DATA

- ACCURACY
- RESOLUTION
- COMPRESSION
- PROCESSING/ENCODING
- ERROR CORRECTING CODES
- STORAGE

AUTONOMOUS OPERATION

- FAULT DETECTION/CORRECTION
- AUTOMATIC OPERATION
- REAL TIME EPHEMERIS (NAV)

TESTING/TESTABILITY

STANDARDS

RECOMMENDATIONS

For each of the problems identified by the working group, recommendations were made for needed technology developments. These recommendations are listed on the following pages. After compiling this list of recommendations, the working group attempted to prioritize these in terms of their need. The prioritization scheme was to use 1 as the highest priority, 2 as a medium priority, and 3 as a lesser priority. Therefore, the recommendations shown have been priority ranked as shown.

For the spectrum overload problem, the working group recommended development of new devices for other frequencies such as the EHF and SHF bands, and the development of laser communications. It was felt that these developments were of the highest priority for solving this problem. The devices for development included antennas, power amplifiers, phase shifters, modulators, VHSIC receivers, detectors, and sources. Of lower priority but still important were the development of higher order modulation schemes. Additionally, it was felt that development of new interference reduction techniques would be beneficial to solving the spectrum overload problem.

For the problem of reliability and survivability, the working group felt that a space-based test platform should be available for proving new TTC concepts. The group felt that as designers, they would be more apt to consider new techniques if these techniques had already been proven in a space environment. The group also recommended establishing a consolidated, high reliability parts program that could be used by industry. The group recommended that standardized design specifications be established for industry to use. Included as part of

these design specifications would be the definition of space environments which also addressed radiation hardness guidelines. The working group felt that different reconfiguration needs of satellites should be examined to try to establish a pattern for needed flexibility. It was not clear how this flexibility could be implemented, but it was unanimous that more flexibility in TTC systems was desired.

In the data handling problem area, the working group felt that new technology was needed with regard to data conversion. Higher speeds of conversion are necessary with more accuracy and higher resolution. To accomplish this, new conversion devices must be developed. The working group also recommended the investigation of new data reduction techniques and development of their corresponding error correction codes. New techniques are needed in the areas of source data reduction, data compression, and on-board data processing. Implementation of these new techniques may require the development of new TTC devices. A final recommendation in the data handling area was to develop higher density, higher access rate, data storage techniques. Promising areas include electronic storage, magnetic storage, and optical storage, or combinations thereof.

For the autonomous operation problem area, the working group recommended the development of automatic navigation systems for spacecraft. Some type of support system is required with the options being GPS stations, earth fixed stations, or other techniques. To accomplish automatic navigation will require on-board processing, receiving, and auto track antenna systems. To enable further autonomous operation, the working group felt that more effort should be conducted in improving automatic fault detection, diagnosis, and correction.

For the testing and testability problems associated with spacecraft, the working group recommended an assessment of emerging techniques for box and system level tests as they might be applied to the TTC subsystem. For the standards problem, it was felt that standard interfaces would go a long way toward making TTC components more applicable to subsystem designs. These standards should address both electrical and mechanical interfaces. It was felt that the development of standard architectures for TTC which were inherently fault-tolerant would be of significant benefit. With such architectures, developers of new spacecraft could implement their systems with the confidence that necessary building blocks would exist.

RECOMMENDATIONS

SPECTRUM OVERLOAD PROBLEM

- 1 ● RECOMMEND DEVICE DEVELOPMENT FOR OTHER FREQUENCIES (EHF, SHF BANDS)
 - ANTENNAS (OMNI, PHASED ARRAY, MULTIPLE BEAM)
 - POWER AMPLIFIERS
 - PHASE SHIFTERS/MODULATORS
 - VHSIC RECEIVERS
- 1 ● RECOMMEND LASER COMMUNICATIONS
 - DETECTORS
 - SOURCES
- 3 ● RECOMMEND INVESTIGATION/DEVELOPMENT OF HIGHER ORDER MODULATION SCHEMES
- 3 ● RECOMMEND DEVELOPMENT OF INTERFERENCE REDUCTION TECHNIQUES

RECOMMENDATIONS (CONT)

RELIABILITY/MATURITY/SURVIVABILITY

- 1 ● RECOMMEND A TEST BED FOR PROOF OF CONCEPT
- 2 ● RECOMMEND ESTABLISHMENT OF A CONSOLIDATED HI-REL PARTS PROGRAM
- 3 ● RECOMMEND ESTABLISHING STANDARDIZED DESIGN SPECS (INCLUDING ENVIRONMENTS)
- 3 ● RECOMMEND DEFINING RADIATION HARDNESS GUIDELINES AND PARTS DEVELOPMENT PROGRAM

FLEXIBILITY

- 3 ● RECOMMEND STUDY TO DETERMINE WHAT THE RECONFIGURATION NEEDS ARE FOR VARYING PAYLOADS

DATA

- 1 ● RECOMMEND IMPROVEMENT IN DATA CONVERSION TECHNOLOGY
 - SPEED
 - ACCURACY
 - RESOLUTION
- 1 ● RECOMMEND INVESTIGATION OF DATA REDUCTION TECHNIQUES AND CORRESPONDING ERROR CORRECTION CODES
 - SOURCE DATA REDUCTION
 - DATA COMPRESSION
 - ON-BOARD DATA PROCESSING
- 1 ● RECOMMEND ADVANCED HI-DENSITY/HI-RATE DATA STORAGE TECHNIQUE DEVELOPMENT

AUTONOMOUS OPERATION

- 1 ● RECOMMEND DEVELOPMENT OF AUTOMATIC NAVIGATION SYSTEM
 - SUPPORT SYSTEM (GPS, EARTH FIXED, OTHER)
 - ON-BOARD SYSTEM (INCLUDING AUTO TRACK ANTENNA)
- 2 ● RECOMMEND DEVELOPMENT OF FAULT DETECTION/DIAGNOSIS/CORRECTION CONCEPT

RECOMMENDATIONS (CONT)

TESTING/TESTABILITY

- 2 ● RECOMMEND ASSESSMENT OF EMERGING TECHNIQUES FOR BOX AND SYSTEM LEVEL TESTS
(FULL COVERAGE TEST VECTORS, PRE AND POST LAUNCH)

STANDARDS

- 3 ● RECOMMEND DEVELOPMENT OF TT&C INTERFACE STANDARDS
(ELECTRICAL AND MECHANICAL)
- 3 ● RECOMMEND DEVELOPMENT OF STANDARD, FAULT-TOLERANT ARCHITECTURES